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TOPEX Microwave Radiometer Thermal Control: Post-System-Test Modifications and On-Orbit Performance

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Abstract

The Topex Microwave Radiometer has had an excellent thermal performance since launch. The instrument, however, went through a hardware modification right before launch to correct for a thermal design inadequacy that was uncovered during the spacecraft thermal vacuum test. This paper reports on how the initially obscure problem was tracked down, and how the thermal models were revised, validated, and utilized to investigate the solution options and guide the hardware modification decisions. Details related to test data interpretation, analytical uncertaint its, and model-prediction vs. test-data correlation, are documented, Instrument/spacecraft interface issues, where the problem originated and where in general pitfalls abound, are dealt with specifically. Finally, on-orbit thermal performance data are presented, which exhibit good agreement with flight predictions, and lessons learned are discussed.

Introduction

The TOPEX/POSEIDON spacecraft was launched on August 10, 1992, from Kourou, French Guiana, by an Ariane 42P rocket to study the earth oceanic circulation and dynamics. Orbiting the earth at an altitude of 1336 km with an inclination of 66°, the satellite has been functioning extremely well. The TOPEX Microwave Radiometer (TMR), as shown in Fig. 1, determines the water vapor content in the troposphere, which is used to improve the accuracy of the sea-surface height measured by radar altimetry. It consists of an antenna, a RF shield, and the main chassis which houses the electronics, wave guides, feed horn and calibration horns. The instrument is mounted on the spacecraft with six titanium struts, is equipped with survival heaters, and relics on two louvered radiators to dissipate a major portion of the 24 W operating power

The TOPEX system thermal vacuum test took place during the period March 24 through April 22, 1992, at the Goddard Space Flight Center (GSFC) facilities. The spacecraft test configurate ion is shown in Fig. 2. The TMR participated in the test without the antenna and the

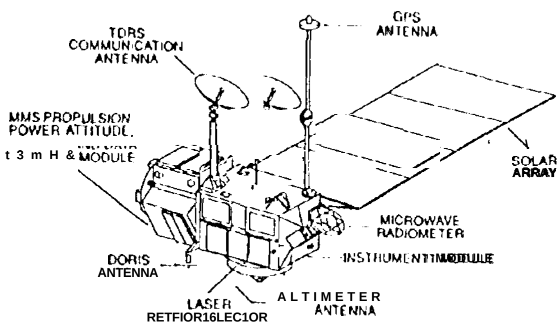

Figure 1. The TOPEX/POSEIDON Satellite

antenna base ring blanket, and with two test targets which were not part of the flight hardware but which were present for performance evaluation purposes (Figs. 2 and 3). The spacecraft was divided into a dozen or so thermal-control zones, and each zone was provided with a plate shroud which was temperature-controlled by the circulating liquid/gaseous nitrogen to simulate the radiation environment. The TMR was assigned two zones, 8A and 8B (Fig. 3). The zone shrouds, together with the vacuum chamber walls, were controlled to pre-determined effective sink temperatures during various phases of the test.

For the TMR, the test results were positive in several respects; i .e., the survival heaters functioned

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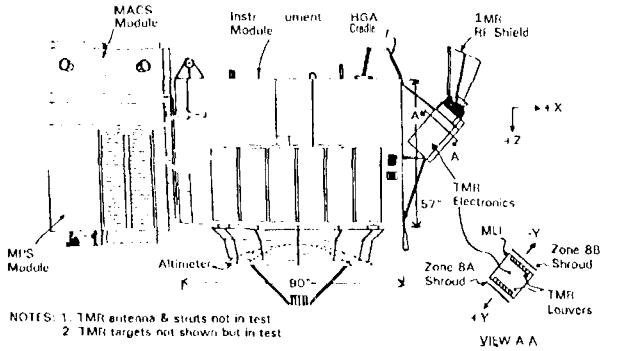

Figure 2. TOPEX Thermal Vacuum Test Configuration (TMR Mounted on the +X Face of the instrument Module)

properly, the louvers opened witbin the expected temperature range, and test data for tbc hot-balance test phases agreed well with model predictions. However, a large discrepancy was noticed between the cold-balance test data and the predictions made by a 20-node reduced model on March 28, 1992. This started a chain of events which included explaining the discrepancy, uncovering the thermal design inadequacy, investigating the solution options, selecting the most practical and low-risk approaches to modify the hardware, and finally implementing the solution. All of this took place within the month between April 20 and May 20, 1992, just in time for shipping the spacecraft to the launch site.

This paper documents these activities and the important technical deliberations that led to the discovery of the thermal design problem as well as the solution. It also reports on in-flight thermal performance of the TMR which has proven to be excellent, attesting the validity of the hardware modifications and all the preceding analyses.

Discovery of the Shading Problem

During tbc cold balance test (March 27-28, 1992), two concerns surfaced. First, the temperature for the Ch1& 4 RF module (or Word 29), a representative electronics temperature, was observed to be 0.9°C. This was significantly lower than the 18°C predicted by the spacecraft contractor (Fairchild Space) using a 20-node reduced model. This large discrepancy, and the fact that the elect ronics were below the 10°C allowable flight limit (later revised to S"C), raised a serious concern. Second, the survival heaters were activated too frequently during the test. Although this was a positive indication that the survival heaters were responsive and would be able to prevent the electronics from falling below 0°C in flight, as intended by design, the frequent on-off switching of the survival heaters might have undesirable effect on TMR data quality.

Regarding the first concern, it was quickly pointed out that the 20-node reduced model for the test configuration (provided by JPL and integrated by Fairchild into the spacecraft model) was never validated, because there were no test data available for validation

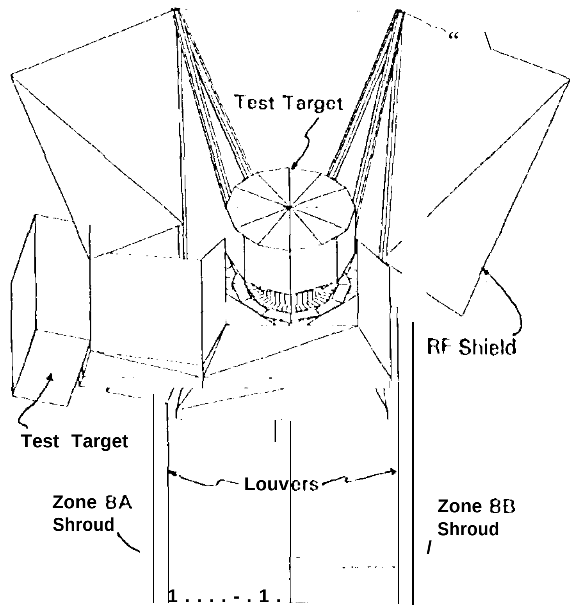

Figure 3. A Plot of the TRASYS Model for the TMR Test Configuration

prior to the system test. Nor was there a detailed model for the test configuration which could bc used as a comparison. Therefore the 20-node model prediction was questionable and could not bc relied upon as the basis of comparison. Consequently, in order to explain the discrepancy and to understand the reasons for the low electronics temperatures, the JPL detailed TRASYS and SINDA models for TM R (248 nodes) were adapted for the test configurate ion, incorporate ing the test targets, the Zone 8 shrouds, and the vacuum chamber (see Figs. 2 and 3). These then became the test models and were used throughout the test for data correlation and interpretat ion.

The results of correlation between the model predictions and test data for eight test cases arc summarized in 'Table 1 (the three JPL test cases have been detailed in Ref. 1.) Table 1 remained valid through April 19, 1992, before the discovery of the shading problem.

Table 1. Interim Correlation of TMR Model Predictions with Test Data*
(As of 4/19/92, before the shading problem was discovered)

Test Case	Chamber Wall T (°C)	Louver Shroud -Z. (°C)	Electronics Temp.$ (°C) Model Pred.	Test Data	ΔT	Test Site#	Remark
1	20	-58	28.8	27.1	1.7	GSFC	1st hot balance
2	21	-4	35.1	37.8	-2.7	GSFC	2nd hot balance
3	2	-190	-2.0	1.2	-4.0	GSFC	Survival heater test
4	0	N/A	29.4	28.3	1.1	JPL	Hot steady state
5	-10	N/A	23.7	20.9	2.8	JPL	Cold steady state
6	-33	N/A	1.9	2.2	-0.3	JPL	Survival mode
7	-50	-185	8.4	0.5	7.5	GSFC	1st cold balance
8	-57	0	21.1	)1.0	10.1	GSFC	2nd cold balance

* The old RF shield model a–rid" a blanket effective emittance of 0.015 were used in the detailed models

$ Ch 1 & 4 RF Module (1A3) temperature, model prediction given by SINDA node 3111, Lest data given by Word 29; $\Delta T = T_{pred} - T_{test}$

\# System-level (satellite) test was done at GSFC (Mar-Apr 1992) and subsystem-level (TMR only) test was done at JPL (Sept 1990).

As can be seen in the Table, all the hot and "miki''cascs (i.e., cases 1 through 6) display good agreement between predictions and data. However, significant discrepancies exist for the cold cases (i.e., cases 7 and 8, where the chamber wall temperature was below -50°C). Incidentally, note that in case 7, which was the first cold balance case to raise concerns on March 28, 1992, the detailed test model predicted 8.4°C for the electronics. This was a substantial improvement over the 20-node model's prediction of 18°C mentioned above. However, the discrepancy of 7.5°C against the data was still troublesome, particularly when viewed together with case 8.

Regarding the second concern, it was noted that the zone 8 shrouds were operated at -185°C during the cold balance test. This caused the louver and radiator temperatures to be low (near 0°C) because the shrouds were only an inch or so away from the louvers. The survival heaters were mounted on the inside of the radiators, and were duly activated by the low radiator temperatures. However, based on effective sink temperatures calculated using flight fluxes obtained from the TRASYS model, the louvers and radiators should face a significantly warmer external environment in flight than the-18S°C shrouds. Therefore, their temperatures should be higher, and the anomaly of frequent activation of the survival beaters should be unlikely during flight. This would be especially true if the electronics temperatures were also higher than observed, Thus both concerns boiled down to the same question, and it was imperative that the causes for the low electronics temperatures be determined.

Fairchild had determined the chamber wall temperatures according to conditions pertinent to the altimeter and the +Z surface[7]. These conditions are not exactly the same as for the TMR. The RF shield temperature had always tracked closely the chamber wall temperature, both in the JPL thermal balance test of September 1990 and the GSFC system thermal test. This meant that during the cold balance tests the RF shield temperature was around -50°C, which was in distinct contrast with previous flight predictions of around -1 S°C. The much colder temperature of the RF shield could certainly drive down the electronics temperatures, because the RF shield was hard-mounted to the TMR chassis and the six aluminum struts would serve as a good conductor of heat from the chassis to the shield, Could it be that the effective sink temperatures employed for the chamber wall and the Zone 8 shrouds were much too cold for the TMR?

Radiant flux comparisons were then made between JPL and Fairchild. It was found that JPL and Fairchild had used exactly the same input flux parameters to the TRASYS program, both for the hot and cold orbits. Also, JPL and Fairchild agreed on the absorbed heat fluxes used for the louvered radiator surfaces. The possibility of shading of the TMR by the HGA (high gain antenna) was suggested by Fairchild, but at $\beta = 88°$ (β being the angle between the sun vector and the orbit plane), this appeared to be either unlikely or insignificant. Finally on April 20, 1992, shading by the MACS module was brought to light. Fairchild faxed JPL two drawings which indicate that the TMR is shaded by the MACS module in the vicinity of $\beta = 88°$ (in terms of Fig. 2, the sun would be coming nearly horizontally from the left.) The MACS shading would be significant, as it would mean that the effective sink temperatures used in the tests were probably not too cold for the TMR. It would also

Table 2. Final Correlation of TMR Model Predictions with Test Data* (As of 5/?0/92, after the shading problem was discovered and the solutions were implemented)

Test Case	Chamber wall T (°C)	Louver Shroud T (°C)	Electronics Temp.$ (°C) Model Pred.	Test Data	ΔT	Test Site#	Remark
1	20	-58	28.8	27.1	1.7	GSFC	1st hot balance
2	21	-4	36.3	37.8	-1.5	GSFC	2nd hot balance
3	2	-190	-6.4	1.2	-7.6	GSFC	Survival heater test
4	0	N/A	29.4	28.3	1.1	JPL	Hot steady state
5	-10	N/A	23.7	20.9	2.8	JPL	Cold steady state
6	-33	N/A	1.9	2.2	-0.3	JPL	Survival mode
7	-50	-185	0.9	0.9	0.0	GSFC	1st cold balance
8	-57	0	17.8	11.0	6.8	GSFC	2nd cold balance

* The new RF shield model and a blanket effective emittance of 0.03 were used in the detailed models

$ Ch 1 & 4 RF Module (1A3) temperature, model prediction given by SINDA node 3111, test data given by Word 29; $\Delta T = T_{pred} - T_{test}$

\# System-level (satellite) test was done at GSFC (Mar-Apr 1992) and subsystem-level (TMR only) test was done at JPL (Sept 1990)

mean that the RF shield would be much colder than previously predicted as the MACS shading was not accounted for in the TRASYS model up till then. The MACS shading problem was confirmed on April 22, 1992, when Fairchild provided satellite dimensions pertinent to the issue.

An examination of a TRASYS cold-orbit run revealed that without the MACS shading, the direct solar load on the RF shield was 142 W, and the albedo plus earth heat load was 17 W; i.e., direct solar was 89% of total. Without shading, the direct solar component had contributed much to warm the RF shield to about -15°C. With shading, direct solar being blocked, the RF shield temperature went down to about -100°C. The nature of the problem was now clear, and the causes for the low electronics temperatures found. In flight, the MACS shading in the neighborhood of $\beta = 88°$ would cause the RF shield to go very cold, and the black-painted aluminum shield and struts would serve as a very effective radiator to dissipate large amounts of heat which would be easily conducted across the struts because of the large temperature gradient set up between the TMR chassis and the RF shield.

Thermal Model Modifications and Validation

To resolve the shading problem, the thermal models had to be modified. A rectangular surface was first added to the TRASYS model to account for the MACS shading at $\beta = 88°$ and vicinity. In the meantime, two additional pieces of information emerged which had an important impact on the assessment being made.

First, two of the six RF shield struts (the "lower" ones that are best connected to the shield) had a thickness of 0.049 in. instead of the 0.030 in, previously communicated to the thermal engineer. This meant that the cross-sectional area for these tubes, and hence their conductance, were actually 59% greater than had been modeled. Second, the TMR will be shaded (by the MACS or the HGA) for a substantial portion of its functional life. This assessment is supported by a TOPEX satellite yaw maneuver packet (made available to the thermal engineer on May 11, 1992). This packet indicates that $\beta = 30°$ to $40°$ has the highest probability of occurrence, and that at $\beta = 40°$, as at other angles, the spacecraft yaw maneuver will be such as to cause the TMR to be shaded most of the time. The implication of this is that the TMR should really be designed more for the cold orbits than for the hot orbits, contrary to previous emphasis.

Thus, it became clear that a careful reexamination must be made of the RF shield design, and the shield might have to be reworked. More details were therefore added to enhance the shield representation. In all, 6 nodes were added to the TRASYS model, and 16 nodes and 27 conductive conductors to the SINDA model.

Another round of model/test correlation was performed subsequent to the model modifications, resulting in Table 2. Besides accounting for some details of the test targets which were not part of the flight models, two additional adjustments on the models were necessary to bring the predictions to a closer agreement

Table 3. TMR Hardware Modification]] Options Analyzed

Case 1.	Baseline (no hardware modification) -- Cold case with MACS shading*
Case 2.	Case 1 + Blanket. on backside of shield$
Case 3.	Case 2 + Al. tape on struts + Paint frontside of shield with D4D (α/ϵ = 0.3/0.3)
Case 4.	Case 2 + Al. tape on struts + Remove paint from frontside of shield and sand surface#
Case 5	Case 4 + G10 washer and Ti fitting on 2 lower struts
Case 6.	Case 5 + G10 washer and Ti fitting on 2 upper struts
Case 7.	Case 6 + Replace 6" of biped with Ti tubes
Case 8.	Case 7 + Replace 6" of 2 upper struts with Ti tubes
Case 9.	Case 5 + complete coverage of -Y side louver with MLI
Case 10.	Case 5 + Partial coverage (71%) of -Y side louver with MLI

* A rectangular surface was incorporated into TRASYS to model shading by the MACS.
$ 20-layers; Cases 1 to 8, ϵ_{eff} = 0.015; Cases 9 and 10, ϵ_{eff} = 0.03.
# Measured optical properties for the exposed aluminum surface are α/ϵ = 0.16/0.04

with the cold-balance data (cases 7 and 8). First, a blanket effective emittance of 0.03 was used instead of 0.015. Second, the conductance between the RF cover and the tophat support in the 4-bolt mounting, area was adjusted upward somewhat. Several significant point are to be noted in comparing Tables 1 and 2 and in interpreting these results:

1. The old RF shield model was adequate if the MACS shading were not a problem. Cases 1 and2 show that the new RF shield model and the higher blanket effective emittance make little difference on the temperature predictions. The JPL test cases were not rerun, but the fact that the RF shield temperatures were mild in these tests (and therefore the ΔT's between the shield and the chassis were relatively small) would argue for similar results.

2. Out of all the test cases listed in Table 2, case 7 with the noted effective sink temperatures, best reflects the MACS shading conditions and provides the best simulation of actual cold orbits for the TMR. The new RF shield model and ϵ_{eff} = 0.03 have a significant impact on the predicted electronics temperature (0.9°C vs. the previous 8.4°C). The same is true for case 8, although Zone 8 shroud temperature being equal to 0°C most probably would not represent any real cold-orbit conditions.

3. An inspection of the raw test data indicated that Case 8 probably did not reach steady state, A smaller ΔT would be expected when steady state is reached. As for case 3, the steady-state analytical treatment of the transient, cyclic situation was approximate. The test data of 1.2°C was an average; the cycling of the beater power was treated by an averaging method based on the on/off periods; and the nodal distribution of the average power was done expeditiously to save time. The ΔT of -7.6°C (although not necessarily regarded as excessive by normal standards) was partially attributable to these approximations, but a more exact treatment of the transient, cyclic situation would have been very time-consuming.

Overall, the correlat ion results shown in Table 2 are quite satisfactory, and the thermal models so validated are considered to be adequate for use in making flight predictions and in guiding the hardware modification effort.

Investigation of Solution Options

Once the MACS shading and the RF shield design were ascertained to be the causes for the unacceptably low electronics temperatures, the solution was obvious. The RF' shield must be conductively decoupled from the TMR chassis or at least rendered ineffective as a radiator. One of the first simulations performed to explore solution options involved replacing all the aluminum struts by titanium ones. With thermal conductivity almost 40 times lower than aluminum, the titanium struts were shown to effectively isolate the RF shield from the TMR chassis. Consequently, whatever happens to the RF shield thermally would not matter much to the electronics. However, extensive discussions involving hardware, project, reliability, and instrument personnel (both Fairchild and JPL) concluded that this approach was not feasible within the known time constraint. A series of alternative options were then investigated, and most of them served to reduce the RF shield's ability to radiate heat.

Table 3 lists the options analyzed, and Table 4 presents the results obtained. It is seen that significant temperature improvements are obtainable by installing an MLI on the backside of the RF shield (9. 5°C), by

Table 4. TMR Temperature Predictions (°C) Associated With Hardware Modification Options As Defined in Table 3

Case	Electronics: CH 1&4 RF Mod (Node 3111)	Electronics: Data Module (node 3126)	RF Shield: Alum. Shield	RF Shield: Backside MLI
1	-8.4	-11.8	13'2.0	N/A
2	1.1	-1.8	-71.8	-140.1
3	6.9	4.2	-61.3	-140.2
4	8.4	5.9	-50,1	-138.3
5	12.1	9.9	-60.2	-140.0
5'#	6.5	3.8	-61.8	-138.7
6	13.2	10.9	-63.4	-140.1
7	14.9	1'2.8	-68.9	-141.2
8	15.4	13.2	-71.5	-141.6
9	17.2$	14.6	-57.7	-138.-/
10	13.9@	11.3	-59.2	-138.-/

#This case has the same hardware modifications as Case 5 except for the following adjustments in the model:
(1) The MLI effective emittance is 0.03 instead of 0.015
(2) Conductance is adjusted between the RF cover and tophat support
$ The corresponding temperature for the hot case is 36.8°C
@ The corresponding temperature for the hot case is 28.6°C

removing the black paint from the frontside of the shield and wrapping the struts with aluminum tape (7.3°C), and by replacing the aluminum fittings with titanium fittings and G10 washers on the two lower struts (3.7°C). Cases 6, 7, and 8 contribute additional gains that are less dramatic than cases 2 through 5. Therefore, during the April 30, 1992 telecon, after extensive discussions involving perhaps 20 or so JPL and Fairchild personnel, it was decided to adopt case 5 as a baseline for implementation. Case 5 predicted, as shown in Table 4, 12.1 °C for the key electronics temperature which was 2°C above the allowable lower limit.

However, subsequent sensitivity study varying the blanket effective emittance indicated that the predicted 12.1 °C for case 5 could be lowered significantly, to 6.5°C as shown in case 5' (Table 4) if $\epsilon_{eff} = 0.03$ (instead of 0.015) and if the conductance between the RF cover and the tophat support was adjusted, as consistent with the final round of model/test correlation which yielded Table 2. Furthermore, information which emerged at this juncture indicated that the TMR would face a cold environment more often than not (as stated in the previous Section). Naturally, a prudent step to take at this point was to seek further improvement which could be implemented within the existing time constraints. Cases 9 and 10 were. then st udicd. They involved covering the -Y side louver with a20-layer MLI fully and partially, respectively. Case 10, with 71% of the louver covered, yielded the most attractive results: 13.9°C for the electronics in the cold case and 28.6°C in the hot case (flight allowables given in a later table).

Note that proper conservatism was exercised in all these analyses. For example, although the actual uncovered (or exposed) louver length is 3.7 in., it was represented in the model as 4.45 in. This was done to account for additional exposure of the louver blades to space due to such deviation from idealization as gaps, shallow-angle view factor, etc. On the hot side, a parametric study was made where the exposed louver area was arbitrarily reduced by 38%. This resulted in the electronics temperature being raised to 30.5°C from 28.6°C. The point of a partially covered louver is that it can still regulate the emissivity so as to prevent excessively high temperature on the hot side (cf. cases 9 and 10).

Hardware Modifications

Consensus building was time consuming. But things moved at a fast pace once the decision was made, and by May 20, 1992, all the recommended hardware modifications were implemented. These included (see Fig. 4 for a picture of the RF shield):

1. Removed all black paint from the RF shield, front and back surfaces, including the struts. The optical properties of the exposed aluminum surface were measured: α/ϵ = **0.16/0.04.**

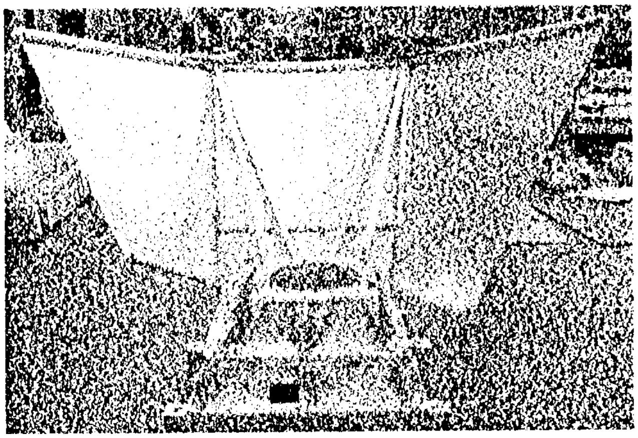

Figure 4, The TMR RF Shield with Its Six Supporting Struts

2. Installed a 20-layer MLI on the backside of the RF shield.

3. Replaced two lower aluminum tube fittings with titanium fittings and G1O washers.

4. Covered 71%, of the -Y side louver with a 20-layer M 1 J. The existing holes cm the louver frame accommodated this readily.

Flight Predictions and Uncertainties

With the above hardware modifications incorporated in the detailed TRASYS and SINDA models, the predicted steady-state temperatures for the Ch 1 &4 RF module during the hot and cold orbits arc:

	Flight Prediction	Allowable limit
not Orbit Max.	29°C	4 0°C
Cold Orbit Min.	14°C	5°C

The allowable operating limits shown above arc as revised on May 22, 1992, following a careful assessment by the project and instrument personnel. (The previous allowable operating range was 10°C to 35°C.)

The margins arc thus seen to bc 11 °C on the hot side, and 9°C on the cold side. These appear to be comfortable margins to account for uncertainties which may arise from various sources: e.g., test configuration being non-flight-like, potential changes in optical and thermophysical properties duc to environmental effects, increased heat loads duc to cont aminat ion, contact conductances and M LI effective emit t ance being imperfectly characterized, cm-orbit anomalies requiring operational changes, and many other unknown factors. The assignment of uncertainty margins can be very subjective. Donabedian[3] reported a 7°C standard deviation between test-correlated model predictions and on-orbit temperature measurements for the Surveyor spacecraft, among other stat ist ics. The TMR margins as indicated above exceed this value.

On-Orbit Thermal Performance

Sine.c TOPEX's launch on August 10, 1992, the thermal performance of the TMR, as well as of the entire spacecraft, has been very sat is factory. The on-orbit temperat urc history of a critical TM R electronic component (i.e., the Ch 1 & 4 RF module) is shown in Fig. 5, Throughout the first 158 days, the temperature has stayed well within the required operating, minimum and maximum, exhibit ing more than 10°C of margin on the hot side, and more than 5°C of margin on the cold side. The temperature peaks typically occurred during the periods when the spacecraft had a fixed-yaw attitude (i .c., Days 30-40, Days 90-103, and Days 138-1 S2), while low t emperat urcs occurred when the spacecraft underwent a sinusoidal yaw maneuver. During the yaw maneuver (for $|\beta| > 20°$ roughly), the spacecraft is typically oriented

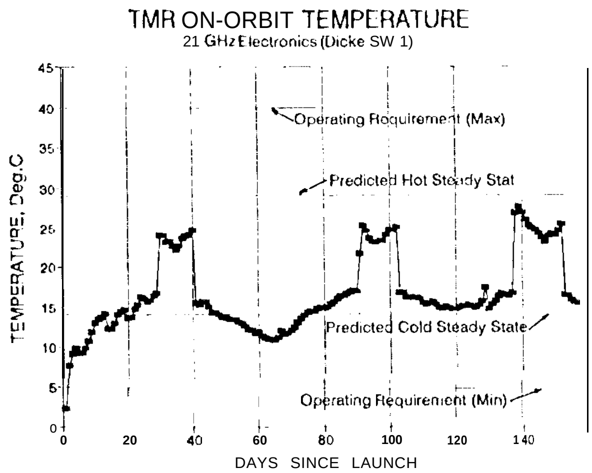

Figure 5. On-Orbit Temperature History for a Kcy TMR Electronic Component

such that the TMR faces away from the sun and is shaded from the back by the spacecraft, hence the lower temperatures. On the other hand, at low beta angles (i .c., $|\beta| \leq 20°$ roughly), the spacecraft dots not yaw and the TMR is exposed to the sun during a portion of the orbit, which explains the higher temperatures. Note that the temperature predictions for both the hot and cold steady states agree closely with on-orbit temperatures.

The temperature trend for the electronics (as exemplified by Fig. S) is corroborated by temperatures for other parts of the TMR; for example, the multi-frequency feed horn, as shown in Fig. 6. In this case, however, no stringent temperature requirements arc imposed. So far, the spacecraft has gone through a wide range of beta angles (-80° $\leq \beta \leq$ + 800). Higher beta angles (i .c., as high as +88°) arc expected to be encountered in 1995. However, it is not anticipated that this will result in any significantly lower temperatures than witnessed in the first 158 days. It is evident that tbc thermal design for the TMR will be adequate for the entire mission. It is also evident that the post-system-test hardware modifications were critical to this successful outcome. Had any of the recommended steps not implemented (especially the last step of covering 71 % of the -Y side louver with MI J), the result would have been violation of the lower operating temperature limit and loss of a considerable amount of data.

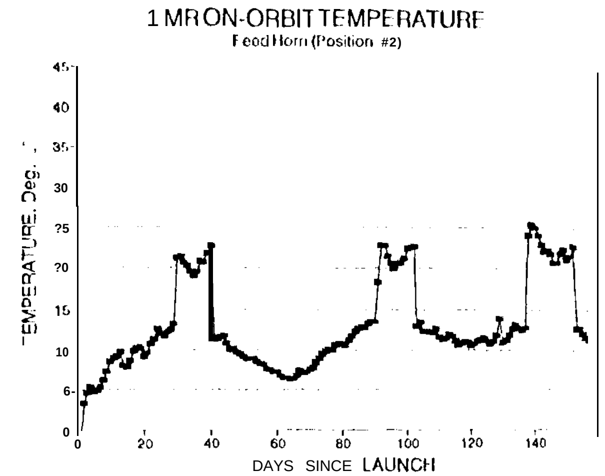

Figure 6. On-Orbit Temperature History for the TMR Multi-frequency Feed Horn

Conclusions

A well planned and executed thermal vacuum test is invaluable and indispensable. While it is highly desirable to make the test configuration as flight-like as possible, where circumstances preclude this, it is still possible to derive important information on the thermal behavior of an instrument (or spacecraft) from a careful analysis of the test data. The discovery of the TMR shading problem and its resolution provides such an example. The intensive test-data vs. model-predictions correlations played an important part in this case, where the analytical models were validated by test data, and subsequently utilized to guide the hardware modification decisions. The analytical predictions carry uncertainties, however, owing to numerous sources as discussed above. This is a fact of reality that must be appreciated, anti reckoned with by a design as robust as practicable. Adequate uncertainty margins arc invariably incorporated into a sound design.

Interface communication is crucial. In a complex project (such as TOPEX) where instrument/spacecraft interface means interface between different companies (or different countries), and where interface between various technical disciplines and administrative units is commonplace, pitfalls abound for communication to break down, Needless to say, a watchful eye, as well as art effective management approach, arc needed to prevent things from falling through the cracks. The TMR experience has underscored the importance of interface communication most emphatically.

As of Day 158, the on-orbit thermal performance of the TMR has been very satisfactory. And by all indications, this should remain true for the rest of the mission.

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